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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

September 12, 2000

Magalie Roman Salas
Office of the Secretary
Federal Communications Commission
445 12th Street, S.W.
TW-A325
Washington, D.C. 20554

Re: ET Docket 98-153
Notice of Proposed Rule Making, FCC 00-163
Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems

To the Commission:

The Aircraft Owners and Pilots Association (AOPA) is the world's largest civil aviation organization representing more than 360,000 pilots who own or fly three-quarters of the nation's 206,000 General Aviation aircraft. General Aviation aircraft comprise 96 percent of the total U.S. civilian air fleet. As the representative of more than one-half of the nation's pilots, AOPA submits the following comments to the Federal Communications Commission's proposal to revise Part 15 of the Commission's rules regarding ultra-wideband transmission systems.

AOPA agrees that UWB technology shows great promise for new applications that provide personal convenience and, in some cases, public safety, but further testing and analysis is needed before the risks of interference from ultra-wideband devices are completely understood. It is clear that these risks of interference, particularly with respect to the Global Positioning System (GPS) receivers, are serious enough to warrant the delay adoption of any rulemaking action and make additional testing analysis an absolute necessity. Failure to do so would jeopardize the massive investment and safety of flight applications that have been implemented utilizing GPS. An example is the use of GPS for Medivac aircraft access to accident or disaster sites. A UWB ground-penetrating viewing device might locate a victim and simultaneously hamper efforts to transport that victim to help.

In conclusion, AOPA strongly urges the Commission to allow adequate time for needed testing and analysis before consideration of any rulemaking and not rush to accommodate a new, enticing technology whose interference characteristics are not well understood. Delaying any action will help ensure that the billions of dollars invested in GPS and the benefits derived therefrom are secure.

Sincerely,

Douglas S. Helton
Vice President
Air Traffic Services and Technology

Enclosure: AOPA Comments, 4 copies

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**Before the**
**Federal Communications Commission**
**Washington, DC 20554**

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In the Matter of

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# COMMENTS OF THE AIRCRAFT OWNERS AND PILOTS ASSOCIATION

## INTRODUCTION AND SUMMARY

The Aircraft Owners and Pilots Association (AOPA) is the world's largest civil aviation organization representing more than 360,000 pilots who own or fly three-quarters of the nation's 206,000 General Aviation aircraft. General Aviation aircraft comprise 96 percent of the total U.S. civilian air fleet. As the representative of more than one-half of the nation's pilots, AOPA submits the following comments on the Federal Communications Commission's proposal to revise Part 15 of the Commission's rules regarding ultra-wideband transmission systems.

AOPA has reviewed docket # 98-153, participated in technical and operational meetings with ultra-wideband (UWB) proponents and various aviation organizations and investigated ultra-wideband technology. In summary, AOPA agrees that UWB technology shows great promise for new applications that provide personal convenience and, in some cases, public safety. AOPA also agrees with the Commission's summary in the notice of proposed rulemaking (NPRM) which states, "Further testing and analysis is needed before the risks of interference [from UWB devices] are completely understood." It is clear that these risks of interference, particularly with respect to the Global Positioning System (GPS) receivers, are serious enough to warrant the delay adoption of any rulemaking action and make additional testing analysis an absolute necessity. We are encouraged by the Commission's commitment to "provide ample opportunity to complete these tests and ensure that analyses of the test results are submitted in the record for public comment before adopting final rules in this proceeding." However, we are concerned that the schedule for submission of tests and analyses called for in the NPRM is unrealistic and that enacting a final rule within this timetable could result in potentially disastrous consequences in the future.

We urge the Commission to allow adequate time to gather and analyze vital information based on sound principles and corresponding tests, rather than rush to accommodate a new and enticing technology whose interference characteristics that are not well understood from the system perspective. These efforts are already well underway. Therefor, AOPA strongly urges the Commission to postpone the enactment of any final rule and initiate a new comment period upon the conclusion of the necessary tests and analyses.

## DISCUSSION AND COMMENTS

**17.** [Paragraph on the Commission's "observation that most UWB devices cannot operate under our current regulations. Therefore, we tentatively conclude that the Commission's rules should be amended to provide for UWB devices.". Also, "any new UWB rule provisions must ensure that radio services are protected against interference"; many NOI comments suggested further testing and analysis is needed; NTIA, DoT and others planning tests. "We plan to allow a reasonable period of time for submittal of test results into the record in this proceeding and will provide an opportunity for public comment on the test results before reaching any conclusions. However, we believe it is appropriate at this juncture to issue a *Notice of Proposed Rule Making* to begin the process of identifying possible rule amendments and alternatives. This *Notice* provides an important framework for considering the various technical issues. We invite broad comment on these issues."]

Comment

a) We agree that ultra-wideband (UWB) devices may offer significant benefits for public safety, businesses and consumers. It is conceivable that UWB technology may find beneficial applications in services involving safety of life and property, including aviation.
b) We agree that the technical nature of UWB devices is such that many, if not most, cannot operate under current regulations. Accordingly, we agree that appropriate amendments to the rules may be necessary to enable operation of those that can, with a high degree of certainty, be demonstrated not to cause harmful interference with existing services in general, and in particular not to cause interference with the services that provide communications, navigation and surveillance (CNS) functions for the aeronautical services. As the Commission states in this paragraph, "...we recognize that any new rule provisions for UWB devices must ensure that radio services are protected against interference."
c) However, we are convinced that the current state of knowledge is inadequate to characterize either the nature of UWB signals or susceptibility of other receivers to them, to the extent necessary to establish amended or new rules. While we agree that a "process of identifying possible rule amendments and alternatives" should begin, we are greatly concerned that a rush to judgment at this stage may lead to derogation of safety services that will not be easily or timely corrected.
d) The Commission also states in this paragraph, "We plan to allow a reasonable period of time for submittal of test results into the record in this proceeding and will provide an opportunity for public comment on the test results before reaching any conclusions. However, we believe it is appropriate at this juncture to issue a *Notice of Proposed Rule Making* to begin the process of identifying possible rule amendments and alternatives. This *Notice* provides an important framework for considering the various technical issues." AOPA believes that the timeline laid out in the NPRM, culminating in the establishment of 30 October 2000 as the cutoff date for test programs and their considered interpretation, is completely inadequate to address the serious issues involved.
e) We respond below to the Commission's detailed requests for comments in the subsequent paragraphs of the NPRM; our detailed comments successively amplify on our broader comments here.

**19.** "We request comment on our proposal to accommodate very low power UWB devices within Part 15 of the FCC rules....We observe that there is insufficient information in the record to address such issues. Accordingly, we are not making any proposals at this time to allow high power UWB devices to operate under Part 15 or on a licensed basis."

Comment

a) We fully agree that there is insufficient information currently available to reach considered conclusions regarding the potential interference effects of UWB devices, or to project how consistency with domestic and international regulations might be achieved. Much depends on the results of the several test programs now in various stages of completion; and at least equally importantly, on the subsequent analysis of those results. It is possible that knowledge gained from those results may indicate that further exploration is necessary. We comment further below on the status of the tests, analyses and conclusions that may be drawn therefrom; and particularly on the time lines apparent when considering the test and analysis processes and the imprudently constrained timelines defined in this proceeding.

b) Accordingly, we concur with the Commission's decision to not make proposals at this time allowing operation of "high-power" UWB devices under Part 15. However, we do not concur with the Commission's proposal to proceed at this time to accommodate "very low power UWB devices", until completed results of the test/analysis programs demonstrate the cumulative effects of such devices do not pose an interference problem with other systems used in aviation.

c) Phrasing of the two categories, "very low power" and "high power", could be construed as leaving a significant middle range of device powers that is not further explicated in the NPRM. Given the current uncertainty of knowledge of possible interference effects on equipment critical to aeronautical safety communications, navigation and surveillance (CNS) applications, and their possible mitigation, we cannot support proceeding with rule making at this time for any UWB devices.

d) We suggest that the "very low power" and "high power" ambiguity can be resolved by simply deleting the word "very". The result would then be clear with two categories of UWB devices, of which the "low power" category contains those devices qualified to the above modified definition, and the "high power" category contains those qualified to criteria yet to be determined. Noting that the Commission anticipates the possibility of yet different qualification criteria for GPRs and similar devices, we believe that this proposal fits the intent of the Commission apparent in the NPRM.

e) When the totality of the potential of UWB technology, beneficial and otherwise, is taken into account, a prudent approach suggests that Part 15 may not be the appropriate home for regulation, at least for "high power" devices. The great difficulties being experienced in attempting to fit UWB characteristics to the existing structures of Part 15, and *vice versa*, are instructive and are well demonstrated by the so-far unanswered issues raised throughout this NPRM.

**21.** [Proposed definition of "UWB devices as any device where the fractional bandwidth is greater than 0.25 or occupies 1.5 GHz or more of spectrum"...based on "the – 10 dB bandwidth rather than the – 20 dB bandwidth"...and "the center frequency of the transmission as the average of the upper and lower –10 dB points, *i.e.*, $(f_H+f_L)/2$." Also, a proposal that "the bandwidth be determined using the antenna that is designed to be used with the UWB device." We invite comment on this proposed definition and whether the fractional bandwidth should be changed to account for the narrower bandwidth that would be measured using the –10 dB emission points instead of the –20 dB points. We request comment on whether we should use some other method to determine the emission bandwidth, such as a calculated bandwidth based on pulse width. We also request comment on whether we should define UWB devices as limited to devices that solely use pulsed emissions where the bandwidth is directly related to the narrow pulse width. Until more experience is gained, we believe that our initial rule making proposals should reflect a conservative approach. In addition, we request comment on whether extremely high speed data systems that comply with the UWB bandwidth requirements only because of the high data rate employed, as opposed to meeting the definition solely from the narrow pulse width, should be permitted. Finally, we request comment on any alternative definitions that may be appropriate."]

Comment

a) We do not agree with the proposed definition of UWB devices for following reasons.
   (1) Current radio regulations are based entirely on the concepts of constraining the implementations of individual services to relatively narrow portions of the radio-frequency spectrum, and corresponding limitations on their spurious "out-of-band" emissions which are

viewed as (more or less) unavoidable byproducts that are undesired by anyone (and hence, are "unintended").

(2) On the contrary, UWB emissions are "intended" and "wanted" in that UWB receivers generally attempt to extract intelligence from all of their signals.[1]

(3) UWB emissions, and their reception, occupy bandwidths that are very much greater than any current service implementation, and even of the total spectrum allocation to any one service.

(4) Enough is now known about the nature of UWB signals to understand that their deleterious effects on other services are such that classic measurement and analytical techniques, and hence classic regulatory criteria, are inappropriate to guarantee the absence of harmful interference. Moreover, enough is now known of receiver processing techniques, including those utilized in UWB devices, to understand that signals that appear to be "buried in the noise" are not only useful (as they are in both UWB and GPS) but can cause serious interference to similar devices.

(5) It is, of course, wholly unrealistic to expect that all other services be altered to accommodate a new unlicensed technology such as UWB.

b) Consequently, a definition of UWB should take into account the nature of UWB devices with respect to the bandwidth of existing services, and the specific assignments and implementations within those services. UWB signals differs fundamentally from the generation of signals by equipment in current services, thus necessitating a way to clearly identify that UWB emitters require non-classical considerations regarding their interference potential. The proposed definition of a fractional bandwidth of 0.25 times the "center frequency" greatly exceeds the former criterion and does not convey the presence of UWB's special characteristics.

c) As to basing the definition of an UWB device on the -10 dB bandwidth rather than the -20 dB bandwidth, we suggest that the identification of a emitting device by its -10 dB bandwidth conveys an overly optimistic impression of the impact of the device as regards its potential interference characteristics. Further, there is a significantly greater possibility of mischaracterization of a device with so small a differentiation of its band edges as -10 dB. This would be particularly true in looking ahead to subsequent questions and issues raised in the NPRM such as testing and qualifying these devices when operated with their intended antennas. Particularly over extraordinary bandwidths, an antenna and associated RF circuitry can be expected to exhibit characteristics that easily could exceed ±5 dB (or even ±10 dB which equals a 20 dB variation). Consequently, we suggest that at least the -20 dB point definition be applied.[2]

d) A corollary is that an effective "center frequency" would be defined as $(f_H+f_L)/2$, where $f_H$ and $f_L$ are defined by their -20 dB points.

e) Closely coupled with these suggestions is our appreciation of the reason the Commission proposed lowering the band edge discriminant to -10 dB; namely, the difficulty of literal and classical measurement of -20 dB spectral points. Indeed, such measurement is likely to be difficult even at -10 dB with many UWB devices that may operate near, at or below the apparent noise floor. This leads us to agree in principle with the Commission's notion of establishing a calculated

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[1] The assumptions supporting this statement are derived from material in the record and otherwise publicly available from proponents of UWB technology, which material characterize an UWB device 's bandwidth as being determined substantially by its antenna. In essentially all cases, the same antenna is used for both transmit and receive functions, and it is further assumed (as is usual) that the antenna is reciprocal. Of course, if additional bandpass filtering were added on the receive side, for whatever reason, then some portion of the emission's spectral width would be unused, hence "unwanted". We urge the Commission to take this possibility into account in its rule-making process.

[2] See also Footnote 1 in these Comments.

bandwidth based at least partially on pulse width. However, we also believe that pulse width alone is not a sufficient metric for establishing "bandwidth" in the sense of a regulatory parameter carrying implications of potential interference, further discussed as follows.

f) The continually increasing complexity of information-bearing RF technologies, combined with the continually increasing hazards of harmful interference, of which the UWB technology is a dramatic example, requires new methodologies for their characterization. In the technical literature, an UWB waveform has been described as having both positive- and negative-going harmonic components, and varying amounts of sinusoid (carrier) damping depending on the driving signal and the transmitting antenna.[3] These attributes suggest a waveform characterization in terms of modulated harmonic components, envelope rise-time, envelope damping based on time-domain measurements of amplitudes. All of these, in conjunction with the PRF and its coding and modulation, have influence on the spectrum of an UWB emission, and hence on its "bandwidth" and potential interference effects.

g) It is desirable that a simpler method of determining bandwidth be defined. Of those methods proposed, the NTIA definition[4] involving pulse width and rise time appears to have the greatest promise in this regard, as it includes both pulse width and pulse shape metrics. We note that this definition is consistent with our view that time-domain measurement techniques are most appropriate for the time-domain phenomena that are at the heart of UWB technology.

h) Regarding the question of determining the bandwidth using the antenna that is designed to be coupled with the UWB device, we believe that this must be done. It appears that the current design philosophy of UWB transmitters is to rely on their associated antennas to establish the waveform characteristics, hence bandwidth, of their emissions. This is in stark contrast with the usual radio transmitter, which establishes its signal in space by means of carefully tuned circuitry self-contained within the transmitter, and which treats antenna coupling as a matter of impedance matching for efficient power transfer.[5]

i) Regarding the request for comment on the further definition of UWB, we suggest that the UWB characterization be limited to devices that solely use pulsed emissions where the bandwidth is directly related to the pulse width and shape. The qualification of "narrow" pulsed emissions should be avoided because the bandwidths would be determined in accordance with the above discussion; the question is begged as to what is "narrow"; and the nature of the impact of such emissions on other equipment, regardless of their bandwidths, should become reasonably predictable as test programs progress. Other techniques for producing very wide bandwidth emissions so defined (e.g., chirping) are likely to have different characteristics with respect to their interference potentials, and possibly could be more amenable to classic analytical, measurement and hence regulatory approaches.

**22.** "In the *NOI*, the Commission noted that Part 15 designates certain sensitive and safety-related frequency bands as restricted bands. Only spurious emissions not exceeding the general emission limits are permitted within these restricted bands...."

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[3] See, for example, U.S. GPS Industry Council and RAND comments on the NTIA test plan, NTIA Docket No. 0006232194-0221-02.

[4] See NPRM, FCC 00-163, footnote 8.

[5] We also have concerns about the implementation of UWB transmission antennas and coupling methods, and the effects of their aging. For example, recent experience with systems operating in the microwave regions has revealed relatively large intermodulation products caused by non-linearity in supposedly passive components such as coaxial cables, connectors, antenna structure fasteners, etc., in situations where peak power levels are in the tens of Watts.

**23.** "Most of the commenting parties agree that the majority of UWB systems cannot avoid transmitting within the restricted bands. In some cases, particularly with ground-penetrating (GPR), it is necessary that the equipment operate in the restricted bands and TV broadcast bands below 2 GHz in order to obtain sufficient ground penetration to detect or image objects. A number of parties raised concerns that UWB devices could cause harmful interference to existing radio operations in the restricted frequency bands, TV broadcast bands, amateur radio frequency bands and others. Several parties raised particular concerns about potential interference to GPS operating in the frequency band 1559 – 1610 MHz. The U.S. GPS Industry Council argues that UWB operation should be limited to spectrum well above 1610 MHz, preferably above 3 GHz, to protect GPS operations from harmful interference. With regard to retaining certain restricted bands, several comments opposed the use of filters to avoid operation within those bands. As stated by Time Domain, the addition of filters to notch out portions of the transmitted spectrum would result in higher cost and would disperse the waveform over time due to complex ringing modes of the filter tuned circuits. Time Domain adds that the requirement to use notch filters would render UWB infeasible by decreasing the signal to noise ratio, reducing available processing gain, decreasing ranging and positioning capability and removing multipath immunity and jamming resistance. MSSI argues that UWB operations should be confined to frequencies above 2 GHz. Interval suggests that we initially allow UWB operations only in the frequency band 2.9-4.99 GHz."

<u>Comment</u>

a) Attachment 1 hereto displays the restricted bands as listed in the Part 15 rules[6] and also identifies the portions of the spectrum used for critical aeronautical purposes (communications, navigation and surveillance -- CNS). It is to be noted that a significant number of aeronautical frequency bands exist above the proposed 2 GHz. To afford no protection for these systems cannot be accepted.
b) Moreover, it is to be noted from Table 1 that a number of the aeronautical systems operate in bands that are partially or completely absent from those listed as "restricted" in Part 15. Consequently, even if Part 15 restrictions were applied at any spectral break point, there would be no protection for some of the critical aeronautical services.[7]
c) Additional comments on this NPRM paragraph are offered under the summary request of NPRM ¶ 25, below.

**24.** "We have considered a number of factors in addressing what frequency bands should be made available for UWB devices. First, we believe that it is vitally important that critical safety systems operating in the restricted frequency bands, including GPS operations, are protected against interference...."

**25.** "...We observe that GPRs must operate at frequencies in the region below 2 GHz in order to obtain the penetration depth and resolution necessary to detect and obtain the images of buried objects. GPRs can neither avoid nor notch out the restricted frequency bands. We believe the risk of interference from GPRs is negligible because the overwhelming majority of their energy is directed into the ground where most of the energy is absorbed. Emissions in other directions can be easily shielded without affecting the operating characteristics of the GPR. In addition, GPRs are expected to have a low proliferation and usually operate at infrequent intervals. Thus, the interference potential of these devices should be low. We also note that, according to the comments, these devices have been used in limited numbers for quite some time for both government and non-government applications without any known instances of harmful interference. Accordingly, we propose to allow GPRs to operate in any part of the spectrum, subject to the emissions limits discussed below. We propose to define a GPR as an UWB device that is designed to operate only when in contact with, or in close proximity (*i.e.*, 1 meter) to, the ground for the purpose of detecting or obtaining the images of buried objects. We also propose to require GPRs to include a switch or other mechanism to ensure that operation occurs only when it is activated by an operator and the unit is aimed directly down at the ground. We invite comment on these proposals."

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[6] 47 CFR § 15.205.

[7] This observation leads us to the conclusion that Part 15 requires revisions irrespective of this proceeding.

Comment

a) We agree, of course, that "the majority of UWB systems cannot avoid transmitting within the restricted bands."[8] However, we do not understand why this is a criterion for regulatory rule making. What is to be avoided is interference, particularly in the restricted bands and on other frequencies that are accorded special measures of protection. Subsequently, the Commission correctly observes, "...we recognize that UWB technology generally cannot completely notch out frequency bands that are a subset of their operating frequencies."[9] The fundamental issue is what degree of filtration is necessary.

b) We completely understand that mitigation of interference potential from these emitters (e.g., power and waveform limitations; high-pass, low-pass, band-pass and/or notch filtering; shielding) can introduce various system operational degradations that may be undesirable, and may also increase costs. However, such penalties are commonly required and accepted for essentially all radiating devices, which also have unavoidable out-of-band emissions. It is not apparent why UWB devices should be exempt from similar restrictions or penalties in order to provide necessary interference controls.

c) Comments on the "emission limits discussed below" are offered under each relevant NPRM paragraph where comments are invited.

d) We agree with operational restrictions for GPR devices, such as those proposed.[10]

e) We question the stipulated proximity (*viz.*, up to 1 meter) to the ground for GPRs that is deemed by the Commission to be adequate to protect critical safety systems. One meter represents the half-wavelength of about 150 MHz. As most UWB GPRs apparently will emit significant amounts, if not most, of their energy above that frequency, the degree of "coupling leakage" and reflection from the ground's surface could be quite substantial. We have not seen discussion on this point in the record.

f) We also respond to NPRM ¶ 26, following, which invites comments on related issues.

**26.** " The situation is less clear with regard to UWB devices that would be used to detect or obtain the images of objects inside or behind walls or other surfaces. In particular, it is unclear whether the same arguments that apply to GPRs concerning penetration depth and resolution similarly apply to other imaging devices. In contrast to GPRs, where signals are aimed at the ground, through-wall imaging devices could aim their energy in any direction. While the wall could attenuate these signals, the amount of attenuation can vary widely depending on the composition of the wall. We note that such systems would be expected to have a low proliferation and would be operated infrequently. One option would be to treat all imaging devices the same way as GPRs. Alternatively, we could restrict the operation of such devices below a certain frequency.We invite comment on these alternatives and any other approaches that may be appropriate. ...Comments also are requested on what provisions are needed to ensure that these systems operate only when they are in contact with a wall. In addition, comments should address whether the operation of through-wall imaging systems should be limited to parties eligible for licensing under the Public Safety Pool of frequencies in Part 90 of our rules, as required under the earlier waiver to Time Domain. Comments also are requested on whether through-wall imaging systems should be required to incorporate automatic power control features that would reduce power levels to the minimum necessary to function based on the composition of the surface and its absorption of RF energy."

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[8] NPRM, ¶ 23.

[9] NPRM, ¶ 30.

[10] Our comments on this issue are amplified in comments on NPRM ¶ 26.

Comment

a) Operational restrictions similar to those proposed for GPRs should be imposed on other UWB imaging devices; indeed, such restrictions would seem to be appropriate for many of the higher-power UWB applications that have been postulated. Among appropriate operational restrictions are limits on those eligible to use such devices.

b) Automatic power control is a technique now commonly employed in modern RF systems, and is necessary to limit intra-system, as well as inter-system, interference potential. A requirement for automatic power control should be a given in any regulation of UWB devices.

**27.** "We observe that most other applications for UWB technology could operate in a variety of regions of the spectrum. To realize the full benefits of this technology, we believe that we should establish as few restrictions as possible on the operating frequencies, except as necessary to protect existing services against interference. We believe that UWB devices can generally operate in the region of the spectrum above approximately 2 GHz without causing harmful interference to other radio services. The UWB signals will quickly fall off below the background noise because of the high propagation losses at 2 GHz and above. Further, most radio services operating above 2 GHz use directional antennas that generally discriminate against reception of undesired signals. Accordingly, we are not proposing any restrictions on UWB devices operating at frequencies above approximately 2 GHz. We invite comment on this proposal."

Comment

The Commission's proposal not to impose any restrictions on UWB devices operating above 2 GHz is unjustified, and particularly so for reasons stated.

d) The realization of supposed benefits of any new (and not well understood) technology cannot be mandated at the risk of interference to existing services.

e) "[A]s few restrictions as possible...except as necessary to protect existing services" does not equate to no restrictions.

f) Among the statements made to support this proposal are, "[w]e believe that UWB devices can generally operate in the region of the spectrum above approximately 2 GHz without causing harmful interference to other radio services", and "[t]he UWB signals will quickly fall off below the background noise because of the high propagation losses at 2 GHz and above." These statements are reflective of the overly simplistic arguments presented by advocates of unrestricted UWB operations, are at odds with early analytical and measurement results, and appear to have been constructed in isolation from the more understanding discussions and questions posed in subsequent paragraphs of this NPRM.[11]

g) A second statement explaining the reasoning for imposing no restrictions on UWB devices above 2 GHz is equally puzzling--"Further, most radio services operating above 2 GHz use directional antennas that generally discriminate against reception of undesired signals." This is a very broad statement that is true only in certain cases and only to some degree. Directional antennas do not "discriminate" undesired signals in the sense of completely rejecting them. Directional antennas can provide a greater ratio of the desired signal to undesired signals only when (1) the desired signal is in the main beam, and (2) when all undesired signals are outside the main beam. This can be the case, but not always, for aircraft CNS system antennas operating with satellites. For aircraft CNS system antennas that look to the ground, including there is no discrimination against any ground-based interference sources also in the main beam. The same observations are

[11] See, in particular, NPRM ¶¶ 31 ff.

generally true of ground-based CNS systems, such as airport surveillance, route surveillance and weather .[12]

h) In all these cases, the degree of discrimination is limited by an antenna's directivity and sidelobe characteristics. Practical levels of off-beam relative attenuation averaged over all space may fall in the range of -3 dB to the order of 20 dB. Considering the high peak power levels (e.g., 1 kW or greater) indicated for some UWB applications and the extreme sensitivity of some aeronautical CNS systems (approaching -200 dBW), such relative attenuation levels are not sufficient grounds to dismiss the interference potential.

i) The state of knowledge regarding the interference effects of UWB emissions indicates that their effects can be manifested at levels far below the average ambient noise level. Systems particularly susceptible to harmful interference from low-level emissions that might appear to be "hidden" in the noise are those systems that employ similar techniques for extracting intelligence from apparent noise, as do UWB and GPS receivers. The techniques are based on the large processing gains (equivalent to reduction of the apparent noise level) that can be achieved through use of sophisticated signal processing devices in the receivers. The processing gain becomes even more powerful when some *a priori* knowledge of the desired signal is available -- as it is with UWB signals and with systems such as GPS, conventional and modern digital communications systems.

j) Harmful interference to such systems occurs when even portions of the undesired signal appear within the expected time and/or frequency domain "windows" expected by the victim system's receiver.[13] The characteristics of the systems potentially most sensitive to low-level UWB signals are primarily those that utilize digital modulation, access and receiver processing techniques, and have relatively wide-band preprocessing bandwidths (relative to classical radio systems).

k) Movement toward systems providing increasingly sophisticated, safety-of-life services via the RF spectrum, while exhibiting greater spectral efficiencies, is inexorable. The protection of such systems is of paramount importance. A better understanding of the deleterious effects of any new kind of system, UWB included, is critical to the avoidance of a disastrous situation in which such services are voided by the existence of unrestricted, and hence unregulated, RF emitting devices. We agree completely with the Commission's statement in NPRM ¶ 21, "Until more experience is gained, we believe that our initial rule making proposals should reflect a conservative approach." Allowing unrestricted operation of UWB devices at this stage, prior to obtaining test data and their interpretations, is clearly not a conservative approach.

**29.** "... We invite comments on UWB operations, potential restrictions on operation for UWB below 2 GHz, and the impacts such restrictions would have on any potential applications for UWB technology. We also invite comment as to the precise frequency below which operations of UWB devices may need to be restricted. For example, should we restrict operations below the GPS band at 1610 MHz, or below the restricted band at 1718.8 - 1722.2 MHz, or below the Personal Communication Service band at 1850 - 1990 MHz, or some other frequency? What should be the limit of any restrictions?"

Comment

a) Our primary response to these questions is contained in our response to the overall proposal and request for comments in NPRM ¶ 27 above. In summary, there are no portions of the spectrum in which unrestricted UWB operations can be justified at this time. Whether the necessary

[12] While GPS receivers are receiving the greatest attention in this proceeding, we wish to emphasize our concern that other sensitive aeronautical CNS systems are being ignored; e.g., current and future satellite-based CNS, airborne and ground-based systems of various types including surveillance, weather and altimeters.

[13] See, for example, the Commission's analysis in NPRM ¶ 36.

restrictions on UWB operations can be effected by existing criteria, such as Part 15, can be determined only through completion of appropriate tests, and the analysis and interpretation of the test data. At the time of submission of our comments, the current efforts of this kind have not been completed and it appears that they will not be completed by the Commission's cut-off date of 30 October 2000. We note the Commission's statement that, "We plan to allow a reasonable period of time for submittal of test results into the record in this proceeding and will provide an opportunity for public comment on the test results before reaching any conclusions."[14]

b) A recent *ex parte* Notice filed by Time Domain Corporation (dated 8/14/2000, containing critiques of the NTIA/ITS and DoT/Stanford test programs) indicates the considerable extent of technical disagreement, among interested and presumably expert parties in this proceeding, that still exists at this late date. Based on these critiques, actions apparently have been taken which will further delay the completion of these programs.

c) We particularly note the Commission's observations within this NPRM regarding UWB devices, "...we find that such applications raise many new and novel questions, such as consistency with the international and domestic table of frequency allocations, and how such services might be licensed to share spectrum across broad frequency ranges used by multiple existing services and licensees. We observe that there is insufficient information in the record to address such issues."[15] We agree with these observations and believe that these issues are of greatest importance. Aviation is a global enterprise; its continued safe and efficient operations impacts all domestic and global economies. Consequently, it is crucial that international radio regulations and those of individual States be adequate to assure continued protection of aeronautical safety services in the presence of UWB devices. It would indeed be unfortunate if the United States led the international community in a faulty direction in this regard.

**30.** "We also wish to consider a number of alternative approaches to expressly prohibiting operations in the frequency bands below 2 GHz. For example, we note that certain UWB applications may be feasible using extremely low signal levels. We invite comment as to whether and at what levels, if any, we should permit operation in the restricted bands below 2 GHz for devices that can operate using extremely low signal levels. While we recognize that UWB technology generally cannot completely notch out frequency bands that are a subset of their operating frequencies, we invite comment as to the viability of establishing a general emission limit for UWB devices below 2 GHz, and whether a very stringent limit, or notch, should be applied to the GPS band. Comments are invited on these alternatives and any others that may be appropriate for regulating the frequencies of operation of UWB devices. Even though we are considering restricting the operation of UWB devices from use below approximately 2 GHz, we will consider allowing access to this spectrum provided that test results and detailed technical analyses are submitted demonstrating that there is no risk of harmful interference to GPS, to other services operating in restricted frequency bands, or to TV broadcasting."

<u>Comment</u>

We address the requested comments in NPRM ¶ 30 in the context of our responses to ¶¶ 27 and 29 above. We strongly oppose the proposal to permit unrestricted UWB operation in <u>any</u> portion of the RF spectrum; and we oppose final decisions at this time regarding specific quantitative restrictions, due to the absence of data and corresponding analyses of the effects of UWB-generated interference to critical aeronautical CNS systems.

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[14] NPRM ¶ 7.

[15] NPRM ¶ 19.

a) It is conceivable that a general set of parametric limits could be established for one portion of the spectrum, and a different set could be established for one or more other portions. It is premature at this time to determine what those parameters and their limits might be, in order to assure protection to the critical aeronautical services. Determination of the parameters is necessary first, before determination of the quantitative limits; and the parameters themselves are at question within the NPRM.[16]

**33.** "...We request that comments discussing interference risk to a particular service identify the specific interference mechanisms they are concerned about and provide the following information, if possible: 1) typical desired signal strengths at receivers in that service; 2) receiver inherent noise level or noise figure; 3) typical antenna patterns for the system and frequency response of the antenna for out-of-band signals indicating expected differential antenna gain for UWB signal and desired signal if applicable; 4) typical front end bandwidths before the first mixer in receivers; 5) typical dynamic range limits of receiver mixers – preferably third order intercept points; 6) typical IF bandwidths; 7) required signal-to-interference ratios for reliable performance of the system assuming interference is white gaussian noise and with others types of interference; 8) required interference to noise ratio; and 9) minimum distance to an interference source that is not under the control of the user....For example, some of the parties filing comments on the NOI felt that emission limits should be based on the unintentional emission limits for digital devices contained in Section 15.109 of our Rules, with a possible adjustment of the quantitative limit. Above 1 GHz, this rule limits average field strength emissions to 150 uV/m at a distance of 10 meters measured over a bandwidth of 1 MHz. We request experiments and comments of whether this framework is an appropriate model for interference potential of UWB signals to other systems. For example, what types of systems are effectively modeled by such a protection criterion? What types of systems need a different type of protection criterion?"

Comment

We fully support the characterization of the susceptibility of critical services to harmful interference from other services. Such data are needed for rational spectrum management currently, and even more so in anticipating the future demands on spectrum management brought about by new services, new technologies for their implementation (e.g., UWB). However, we note that differing implementations and associated equipment within a given service are likely to have different modes and levels of susceptibility, requiring a more detailed view than for only a service *per se*.

a) The listing of proposed parameters (1 through 9) are sufficient for establishment of classic interference criteria; i.e., in those cases where consideration of average spectral power densities of system noise, desired signals and undesired signals is appropriate. As previously discussed, this appears to be not the case where the undesired signals are wideband and digitally modulated (e.g., UWB) and where the victim receiver employs wideband, digital information bearing and extensive receiver signal processing technologies. The vulnerability of such a receiver appears to be greatest when the effective PRF of an UWB signal is within the bandwidth of the receiver.[17]

b) GPS receivers fit the latter definition and are currently under intensive investigation in these regards. Another example with similar characteristics is the current Aeronautical Mobile Satellite (R) Service (AMS(R)S), which provides aeronautical safety communications via satellite. AMS(R)S receivers operate in a frequency band close to GPS, have front-end bandwidths of 30 MHz, provide simultaneous multi-channel communications through extensive processing of the front-end signals, and have sensitivity values closely approximating GPS. The RTCA is

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[16] NPRM ¶¶ 33-57; e.g. ¶¶ 33 & 35 for quantities, ¶52 for measurement/definition in the time by time-domain voltage peak measurements.

[17] The preliminary DoT/Stanford test results, the discussion in NPRM ¶ 33 and the example in its footnote 47 illustrate these attributes.

developing susceptibility characteristics of AMSS/AMS(R)S receivers using criteria including those listed in NPRM ¶ 33, plus consideration of the ITU recommendation[18] of a single-entry interference limit of 6% $\Delta T/T$. Hence that information (expected to be made available in late 2000 or early 2001) will be of interest to the Commission as one response to its request. Near-final results indicate an interference power limit of -163.2 dBm at the receiver input port in the band 1529-1560 MHz, linearly (in dB) increasing to +3 dBm at 1450 MHz and 1226.5 MHz; and level at +47.8 dBm in the band 1626.5-1660.5 MHz, dropping to +3 dBm at 1660.5 MHz and above.[19] However, the AMSS/AMS(R)S susceptibility information is based on the classic criteria mentioned above, which is valid only in the current environment of interfering signals that can be treated as equivalent to noise. Susceptibility of AMS(R)S to signals of the UWB class has not been investigated.

**36.** "We tentatively conclude that it is necessary to regulate both the peak and average emission levels above 1 GHz and the quasi-peak emission levels below 1 GHz from UWB transmitters, just as we regulate these emission levels for most other types of Part 15 transmission systems. The impact of UWB signals on a receiver appears to depend on the randomness of the UWB signal and the relationship between the pulse repetition frequency (PRF) of the UWB signal and the bandwidth of the receiver. If the UWB pulses are spaced evenly in time and each pulse is exactly the same (as in many systems), then classic communications theory shows that the spectrum consists of narrow spectral lines spaced at the PRF. The impact of these signals on a receiver can be modeled by treating each spectral line as a narrow-band conventional signal. This gives rise to one possible way to increase protection to GPS receivers from UWB GPR and through-wall imaging devices. Since repetitive identical pulses are often applicable to GPRs and through-wall imaging devices, it may be possible for designers to select system parameters to avoid GPS signal bands and thus avoid co-channel interference. It also may be possible to space the UWB signal's spectral lines in places within the GPS band where GPS receivers are less sensitive to interference. We request comment on whether this technique is applicable to all types of GPRs and through-wall imaging devices and the cost implication of using a stable frequency reference to ensure the PRF creates a signal avoiding the GPS bands."

Comment

a) We find merit in the Commission's tentative conclusion, "...it is necessary to regulate both the peak and average levels above 1 GHz, and the quasi-peak emission levels below 1 GHz from UWB transmitters...."

b) This conclusion is related to the characterization of UWB-like signals and receivers that are most likely to experience harmful interference situations, discussed above, and the fact that the bandwidths of receivers in services operating below 1 GHz are likely to be relatively small. Further, the Commission's observation that, "[t]he impact of these signals on a receiver can be modeled by treating each spectral line as a narrow-band conventional signal," leads directly to an understanding of why comparison of the average power spectral densitiy of an UWB signal and the average victim system noise power is of little value in determining, or regulating, UWB interference.

c) Viewing each spectral line as a narrow-band conventional signal also illustrates why GPS receivers are particularly vulnerable to seemingly small UWB interference. Many higher-end GPS receivers, such as are in use for aeronautical navigation purposes, use greater bandwidths to capture the farther-out spectral lines of the GPS signals, in order to increase the precision of pseudo-range measurements. These GPS signal sidelobes have much lower signal energy than the nearer sidelobes and hence are more vulnerable to interference. Consequently, one or more very

[18] ITU Recommendation M.1234.

[19] RTCA Paper SC-165/WG1-WP/485.

low-level UWB spectral lines falling on the higher-order GPS sidelobes can degrade or completely negate the additional precision needed for critical operations such as Category II or III landings.

d) Moreover, the treatment of each spectral line as a narrow-band conventional signal in this manner opens the possibilities of measurement and regulatory criteria that will truly take into account the degradation of a service in consideration of harmful interference. As the Commission, and the community, are searching for the appropriate qualification criteria for a new class of emissions, it would seem that herein lies an appropriate approach.

e) Regarding the suggestion that "it may be possible to space the UWB signal's spectral lines in places within the GPS band where GPS receivers are less sensitive to interference", we consider such a technique to be infeasible, even for a fixed GPS receiver, due to the varying Doppler shifts of the GPS signals in space. Further, the motion of aircraft with respect to both the GPS satellites and sources of UWB emissions results in differing instantaneous Doppler shifts of each discrete GPS and UWB signal, resulting in smearing of the combined signals in space which cannot be resolved.

**37.** "... We seek comment on whether we should require such scrambler technology for UWB communications systems or, alternatively, a performance requirement that would show that the transmitted spectrum remains noise like in the case of unchanging input data."

Comment

As this request for comments follows that of NPRM ¶ 36, we believe that the Commission may foresee answers to the questions posed in ¶ 36. However, the issues involved are complex.

a) Given that interfering signal spectral lines falling on desired signal spectral lines can cause unacceptable receiver performance degradation, in the manner discussed under NPRM ¶ 36, sufficient dithering or scrambling of the interfering signal spectral lines in the instantaneous time/frequency domains would decrease the probability of harmful interference, given that (1) the interferor bandwidth is sufficiently wide to have narrow spectral line occupied bandwidth, (2) the receiver processing discriminates signals in the desired signal's interstitial regions, and (3) there is a significant ratio of spacing of desired signal's spectral sidelobes to their occupied or filtered bandwidth. In the case of GPS, the filtering bandwidth is about 50 Hz, and the spacing is about 1 kHz, which could provide for some measure of protection.

b) Alternatively, given the same single interferor and victim receiver characteristics as in (a) above, it is conceivable that the (very stable) PRF of the interferor could be adjusted such that the interfering spectral lines do not occupy the same frequencies as the desired signal's spectral sidelobes. The difficulty in this approach is that the interfering PRF would have to be very stable, which likely to generate complaints regarding associated costs.

c) While the above techniques might be effective for a single UWB interferor, there is a major issue in applying either technique in the case of multiple interferors. In the first case, random (and perhaps coded) dithering would likely increase the probability of harmful interference, as the occupied spectrum of the aggregate interfering signals would be increased. In the second case, full effectiveness of the technique might require synchronization of a large number of proximate UWB devices--perhaps difficult under the economic constraints that have been argued for UWB devices.

**39.** "...For emissions from UWB devices other than GPRs and, possibly, through-wall imaging systems, we tentatively propose that emissions that appear below approximately 2 GHz be attenuated by at least 12 dB below the general emission limits. We believe that this attenuation below the general emission levels will provide additional protection to the congested spectrum below 2 GHz without affecting the viability of UWB operations. Comments are requested on whether such an attenuation level is necessary, or whether additional attenuation below 2 GHz is possible or necessary. We also seek comment on whether the proposed reduction in the emission levels should apply to all emissions below 2 GHz or only to emissions below 2 GHz that fall within the restricted bands shown in 47 C.F.R. § 15.205. Comments also are requested on whether UWB devices other than GPRs, and possibly through-wall imaging systems, should be permitted to operate below 2 GHz provided they comply with these reduced emission levels. Commenting parties should address any additional changes to the technical standards or to the operational parameters of UWB transmitters that could be employed to facilitate the operation of these products below 2 GHz."

Comment

As commented above, we do not agree that the current state of knowledge is such that detailed emission levels can be established that will provide protection of critical safety services. However, we again object to the focus on establishing emission limits only below 2 GHz.

**42.** "...[W]e propose two methods of measurement: 1) the peak level of the emission when measured over a bandwidth of 50 MHz which we believe is comparable to the widest victim receiver that is likely to be encountered, and 2) the absolute peak output of the emission over its entire bandwidth. Comments are requested on the suitability of these two measurements with regard to the potential for interference from UWB transmitters to wideband receivers used in the licensed radio services."

Comment

a) With respect to the extant aeronautical services using the radio spectrum, we would agree that an assumption of a 50 MHz receiver bandwidth is reasonable. This value is ample for current GPS, GLONASS and AMS(R)S receivers (which have a "front end" 1 dB bandwidth of 30 MHz). Thus, specification and measurement of the peak level of emission within a 50 MHz bandwidth would be appropriate for protection of current services.
b) However, looking to the future for more efficient utilization of the spectrum through sophisticated technology, just as the Commission is looking to the future for UWB technology, it is possible that substantially greater receiver bandwidths may be necessary. For example, if UWB should prove to have operational and spectrum efficiency advantages for communications, ranging and imaging applications, it is conceivable that UWB-like technology could become desirable for aeronautical CNS functions -- in which case UWB-like bandwidths would be necessary. In the latter case, the absolute peak output of emission would be more appropriate as a conservative measure.
c) We observe that neither approach is mutually exclusive, that requiring measurement of both peak emitted level in 50 MHz and peak level across a device's entire bandwidth is not overly onerous, and that both measures will have their utility in characterizing interference potential of devices using the novel UWB technology. This observation is also applicable to the considerations expressed in NPRM ¶ 55.

**44.** "We do not believe that allowing such a high absolute peak signal relative to the Part 15 average limit will significantly increase the potential for harmful interference to other radio operations due to the wide spreading of the transmitted energy that is being required. We request comment as to whether the higher absolute peak limit will cause increased interference problems, especially using the proposed measurement procedures described below and with the limitations on frequency bands of operation described above. Comments are requested on the proposed method of varying the absolute peak emission limit and whether other features, such as the excess bandwidth, *i.e.*, the amount of the occupied bandwidth/effective data rate exceeds a specified level such as 10 dB, should be employed in calculating a peak limit. Comments also are requested on whether wideband receivers used in the licensed services are sensitive to peak signal level in a unit bandwidth, such as the 50 MHz reference above, or to the total peak emission produced by the USB device, and whether both peak limits are needed to reduce potential interference to the authorized radio services. If only one peak limit is needed, the comments should indicate which limit is appropriate. We intend to rely heavily on submitted test data in determining what peak emission standards should apply to UWB products."

Comment

Current indications are that the degree of the interference impact of UWB devices is directly related to peak levels of undesired signals. The issues of peak level per 50 MHz and absolute peak level is discussed in our response to NPRM ¶ 42 above.

**45.** [Not quoted]

No comment.

**46.** "Cumulative impact....For example, how does the cumulative impact of those UWB transmitters that emit a line spectrum compare to those that have a high level of random pulse positioning or dithering and may appear as Gaussian noise? Further, what is the relationship between pulse repetition frequency and the cumulative impact of a number of UWB devices? We look forward to receiving comments and test data from various parties along with relevant input from the Commission's Technical Advisory Council."

Comment

We are very concerned about the aggregate interference that may result from a number of UWB emitters not only from the perspective of aggregate interference power, but also from the perspective of the way that UWB signals affect desired signals in correlative receivers (e.g., GPS and ). Contemplating the broad applications foreseen for UWB devices (e.g., high-speed wide-area networks, wireless high-speed local area networks, sensors for numerous consumer and industrial applications), the quantities even in localized areas could be very large.

a) The imposition of one or more UWB line spectrum components on one or more of a victim's desired signal line spectrum components can cause unacceptable degradation when the receiver is tracking, and can cause failure of reacquisition of track were lost.
b) The efficacy of PRF dithering or like alternatives is questionable, as outlined in our responses to NPRM ¶¶ 36 and 37.
c) particularly with respect to aeronautical systems. Aviation receivers must contend with Doppler shift of signals in both air-to-ground and ground-to-air directions, correction of which is increasingly problematic at higher frequencies, with wider bandwidths, and with signal processing sophistication (as with GPS, , microwave landing systems, AMS(R)S, etc.). The situation is exacerbated when the corresponding transmitters also are in motion, as is the case with satellite-based systems such as GPS and next-generation satellite communications.

**47-54.** [Paragraphs inviting comments not quoted.]

Comment

We offer no specific comments on NPRM ¶¶ 46 through 54.

**55.** "... However, we are concerned that a manufacturer could employ a low frequency carrier with an extremely narrow pulse or a narrow pulse impulse system could be used with a low frequency antenna, resulting in emissions extending far beyond the tenth harmonic, the normal upper range of measurement. Accordingly, comments are requested on whether a different method of determining the frequency measurement range should be employed, *e.g.*, a system based on pulse rise time and width. In addition, commenting parties should note that the lower frequency range of measurements would continue to be determined by the lowest radio frequency generated in the device. Comments are requested on whether the pulse repetition frequency, pulse dithering frequency, modulating frequency or other factors would permit the investigation of a low enough frequency range to address possible amplification of the emitted signal due to antenna resonances below the fundamental emission."

Comment

For these as well as other reasons previously discussed, we believe that UWB emissions must be characterized by their time-domain properties as well as frequency-domain properties. It is essential to account for the lowest frequency present, as well as the highest frequency that is of significance regarding interference potential.[20]

**57.** "Except for MSSI, all of the comments agreed that we should eliminate the prohibition against Class B, damped wave emissions as this does not appear to be relevant at the power levels being proposed for UWB transmissions. We agree. These levels appear to be low enough to prevent harmful interference to other users of the spectrum. Further, unlike conventional damped wave transmissions it is likely that the receivers associated with UWB transmitters would attempt to recover as much of the transmitted bandwidth as possible for information processing purposes. Accordingly, we propose to eliminate this prohibition for UWB transmitters, and seek further comment on this proposal."

**59.** "We propose to require that the regulations proposed in this *Notice* become effective 60 days from the date of publication of the Report and Order in this proceeding in the Federal Register. Comments are requested on this proposed transition provision."

Comment

As there is significant and warranted doubt that the regulations proposed in this notice are adequate to protect aeronautical safety-of-life and safety-of-property communications, navigation and surveillance functions, the proposed transition provisions are unacceptable until such time that reasonable agreement of the aviation community can be achieved as to their effectiveness, either as proposed in the NPRM or as suitable modified.

**Appendix A.** "As required by Section 603 of the Regulatory Flexibility Act,[21] the Commission has prepared an Initial Regulatory Flexibility Analysis (IRFA) of the expected significant economic impact on small entities by the policies and rules proposed in this *Notice of Proposed Rule Making ("Notice").* Written public comments are requested on the IRFA. Comments must be identified as responses to the IRFA and must be filed by the deadlines for comments on the *Notice* provided above."

Comment

Regarding IRFA, the impact on small entities of the policies and rules proposed in this *Notice of Proposed Rule Making* cannot be estimated at this time. Substantially all of the AOPA's constituency is small entities, comprising individuals and small businesses who are aircraft owners and operators. The specialized services and provisions required by these owners and operators are, in turn, delivered substantially by small entities. Should the proposed rules be rushed into effect, and their inadequacies to protect aeronautical safety-of-life-and-property communications, navigation and surveillance functions were discovered some time later, the only timely response would be to curtail aeronautical

[20] The possibility outlined in this paragraph is another reason why we question the proposed definition of 10 dB bandwidth for UWB devices (see NPRM ¶ 21).

[21] *5 U.S.C.* § *603.*

operations in an appropriate manner. The resultant impact on small entities would be severe and long-standing.

**ATTACHMENT 1**

**Comments of the National Business Aviation Association, FCC 00-163**

Comparison of Current 47CFR § 15.205 "Restricted Frequencies" with frequencies utilized by aeronautical safety services. Those aeronautical frequencies not included in § 15.205 are indicated by shaded cells in the "Part 15" columns.

| **Part 15 Restricted Frequencies (MHz)** | | **Aeronautical Frequencies (MHz)** |
|---|---|---|
| Low | High | |
| 0.090 | 0.110 | Omega, LORAN-C |
| | | NDB: 0.19-0.435 |
| 0.495 | 0.505 | |
| | | NDB: 0.510-0.535 |
| 2.1735 | 2.1905 | AM(R)S (HF MWARA/LDOC, etc.) |
| | | AM(R)S (HF MWARA/LDOC, etc.) 2.850-3.025 |
| 4.125 | 4.128 | |
| 4.17725 | 4.17775 | |
| 4.20725 | 4.20775 | |
| | | AM(R)S (HF MWARA/LDOC, etc.) 4.650-4.700 |
| | | AM(R)S (HF MWARA/LDOC, etc.) 5.480-5.680 |
| 6.215 | 6.218 | |
| 6.26775 | 6.26825 | |
| 6.31175 | 6.31225 | |
| | | AM(R)S (HF MWARA/LDOC, etc.) 6.525-6.685 |
| 8.291 | 8.294 | |
| 8.362 | 8.366 | |
| 8.37625 | 8.38675 | |
| 8.41425 | 8.41475 | |
| | | AM(R)S (HF MWARA/LDOC, etc.) 8.815-8.965 |
| | | AM(R)S (HF MWARA/LDOC, etc.) 10.005-10.100 |
| | | AM(R)S (HF MWARA/LDOC, etc.) 11.275-11.400 |
| 12.29 | 12.293 | |
| 12.51975 | 12.52025 | |
| 12.57675 | 12.57725 | |
| | | AM(R)S (HF MWARA/LDOC, etc.) 13.260-13.360 |
| 13.36 | 13.41 | |
| 16.42 | 16.423 | |

| Part 15 Restricted Frequencies (MHz) | | Aeronautical Frequencies (MHz) |
|---|---|---|
| Low | High | |
| 16.69475 | 16.69525 | |
| 16.80425 | 16.80475 | |
| | | AM(R)S (HF MWARA/LDOC, etc.) 17.900-17.970 |
| | | AM(R)S (HF MWARA/LDOC, etc.) 21.924-22.000 |
| 25.5 | 25.67 | |
| 37.5 | 38.25 | |
| 73 | 74.6 | |
| 74.8 | 75.2 | ILS Marker Beacon |
| 108 | 121.94 | ILS localizer, VOR, AM(R)S (VHF A/G) |
| | | AM(R)S (VHF A/G) 121.94-123 |
| 123 | 138 | AM(R)S (VHF A/G) |
| 149.9 | 150.05 | |
| 156.52475 | 156.52525 | |
| 156.7 | 156.9 | |
| 162.0125 | 167.17 | |
| 167.72 | 173.2 | RCOM, Maint/Security, point-to-point |
| | | RCOM, Maint/Security, point-to-point (173.2-174 missing) |
| 240 | 285 | |
| 322 | 335.4 | ILS Glide Slope |
| 399.9 | 410 | Wind Profiler , Maint/Security, point-to-point |
| | | Maint/Security, point-to-point 410-420 |
| | | PLMR ATU 406.0-406.1 |
| | | Maint/Security, point-to-point 406.1-420.0 |
| | | Wind Profiler 449 |
| 608 | 614 | |
| | | Wind Profiler 915 |
| | | LDRCL (RMM) 932-935 |
| | | LDRCL (RMM) 941-944 |
| 960 | 1240 | TACAN, DME, ARSR, ATCRBS, Mode S, TCAS, IFF, GPS L5 & L2; |

| Part 15 Restricted Frequencies (MHz) | | Aeronautical Frequencies (MHz) |
|---|---|---|
| Low | High | |
| | | Galileo E5 |
| | | ARSR (1215-1400)<br>1240-1300 piece missing) |
| | | GLONASS<br>1240-1262 (pre 2005)<br>1238-1254 (post 2005) |
| 1300 | 1427 | |
| 1435 | 1626.5 | GPS L1, GLONASS<br>AFRTCC (telemetry)<br>AMSS/AMS(R)S (downlink)<br>AMSS/AMS(R)S 1610-1626.5 |
| | | AMS(R)S (uplink)<br>1626.5-1645.5 |
| 1645.5 | 1646.5 | |
| | | AMS(R)S (uplink)<br>1646.5-1660 |
| 1660 | 1710 | |
| | | LDRCL<br>1710-1850 (pieces missing) |
| 1718.8 | 1722.2 | |
| 2200 | 2300 | |
| 2310 | 2390 | AFRTCC (telemetry) |
| 2483.5 | 2500 | |
| 2655 | 2900 | ASR, NEXRAD (partial) |
| | | NEXRAD<br>2700-3000 (2900-3000 missing) |
| 3260 | 3267 | |
| 3332 | 3339 | |
| 3345.8 | 3358 | |
| | | ASR expansion band<br>3500-3700<br>(3500-3600 missing) |
| 3600 | 4400 | ASR expansion band (3600-3700)<br>Altimeters (4200-4400) |
| | | |
| 4500 | 5150 | ARNS (5000-5150 with sharing in some parts with AMS(R)S, FSS, RDSS) |
| 5350 | 5460 | Airborne & beacons |
| | | TDWR<br>5600-5650 |
| 7250 | 7750 | RCL, TML |
| | | RCL, TML<br>(7750-8025 missing) |

| Part 15 Restricted Frequencies (MHz) | | Aeronautical Frequencies (MHz) |
|---|---|---|
| Low | High | |
| 8025 | 8500 | RCL, TML |
| | | Airborne<br>8750-8850 |
| 9000 | 9200 | PAR |
| 9300 | 9500 | Airborne and beacons |
| 10600 | 12700 | |
| 13250 | 13400 | Airborne |
| 14470 | 14500 | TML |
| | | TML<br>(14500-15350 missing) |
| 15350 | 16200 | ALS, MSBLS, ASDE-3 |
| | | ASDE-3<br>(16200-17700 missing) |
| 17700 | 21400 | |
| | | LDRCL<br>(21200-22010 missing) |
| 22010 | 23120 | LDRCL<br>21200-23600 |
| | | LDRCL<br>(23120-23600 missing) |
| 23600 | 24000 | ASDE-2 |
| 31200 | 31800 | |
| | | Synthetic/Enhanced Vision Systems (generally, -like systems)<br>34700-35200 |
| 36430 | 36500 | |
| | | Synthetic/Enhanced Vision Systems (generally, -like systems)<br>92000-95000 |
| | | |